Snow cover variations and controlling factors at Upper Heihe River Basin, Northwestern China

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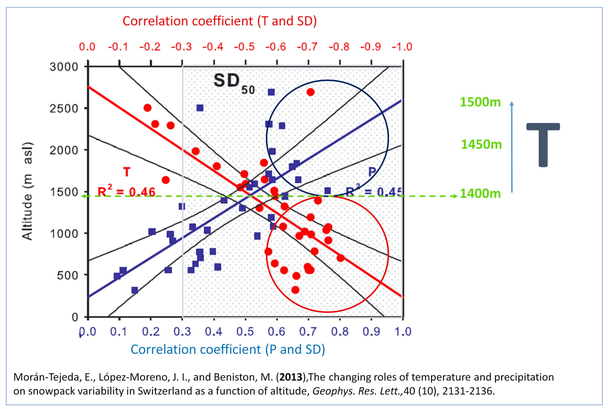
Introduction

Snow is an important water resource and greatly influences water availability in the downstream areas. In this study, snow cover variations of the Upper Heihe River Basin (UHRB) during hydrological years (HY) 2003 – 2013 (September through August) is examined using the flexible multiday-combined MODIS snow cover products. It is found that spatial distribution and pattern of snow cover from year to year for the basin is relatively stable, with maximum snow cover area (SCA) and snow cover days occurring in HY2004, HY2008 and HY2012. A method, based on correlation coefficients between SCA and climate factors (mainly air temperature and precipitation), is presented to identify the threshold altitude that determines contributions of climate factors to SCA. A threshold altitude of 3650 (± 150) m is found for the UHRB, where below this altitude, both air temperature (T_{air}) and precipitation are negative factors on SCA, except in the winter season when both are positive factors. Above the threshold altitude, precipitation acts as a positive factor except in summer, while T_{air} is a negative factor except in autumn. Overall, T_{air} is the primary controlling factor on SCA below the threshold altitude while precipitation is the primary controlling factor on SCA above the threshold altitude.



Morán-Tejeda, E., López-Moreno, J. I., and Beniston, M. (**2013**),The changing roles of temperature and precipitation on snowpack variability in Switzerland as a function of altitude, *Geophys. Res. Lett.*,40 (10), 2131-2136.

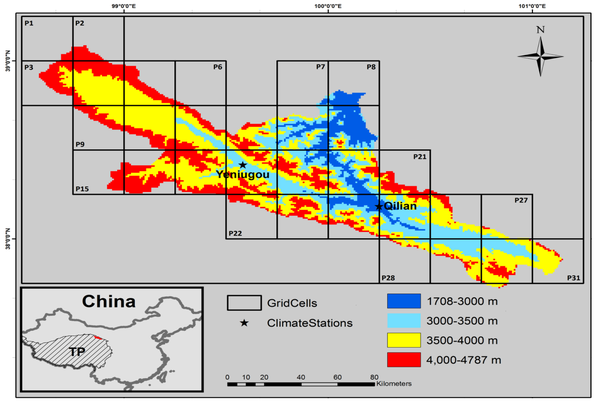


Figure 1. Drainage basin of the upstream Hehei River over Tibetan Plateau (shadow area), with two weather stations: Qilian (2787m) and Yeniugou (3320 m) denoted as black stars. The basin is segmented as four elevation zones: 1708m - 3000 m, 3000 m -3500 m, 3500m - 4000 m, and 4000 m -4787 m. The 31 grid cells (25 km × 25 km) are precipitation cells.

Methods

Calculation of SCD

Snow covered days (SCD) is defined as the total number of days that a pixel covered with snow in a hydrological year.

$$\mathrm{SCD}_j = \sum_{i=1}^{365} \mathrm{Cell}_i \quad (\mathrm{Cell}_i = 0 \text{ or } 1) \qquad (1)$$

Estimation of Air Temperature from LST

$$T_{air} = b_0 + b_1 \times LST \qquad (2)$$

The relationships between Land Surface temperature (LST) and air temperature (T_{air}) for the QiLian and YeNiuGou stations for both snow-covered and no-snow conditions are displayed in Figure 5. A considerably greater amount of scatter exists for the no-snow conditions (Figure 5b, d) compared to snow-covered conditions (Figure 5a, c).

Results

Snow Cover Dynamics

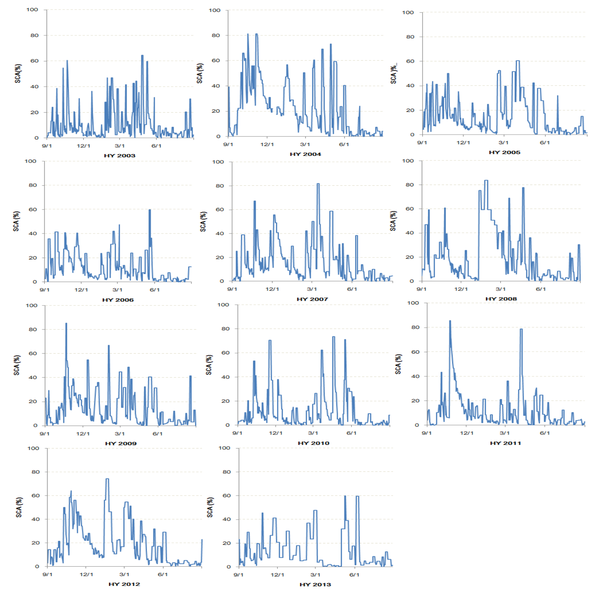


Figure 2. Time series of snow cover area over the basin area (%) from flexible multiday combined MODIS images, in the upstream of Hehei River basin during HY2003–2013.

Seasonal Means of SCA

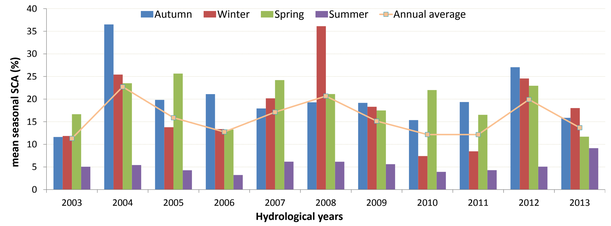


Figure 3. Mean seasonal and annual SCA (%) in the upstream area of Heihe River during HY2003–2013

Spatial Distribution of SCD

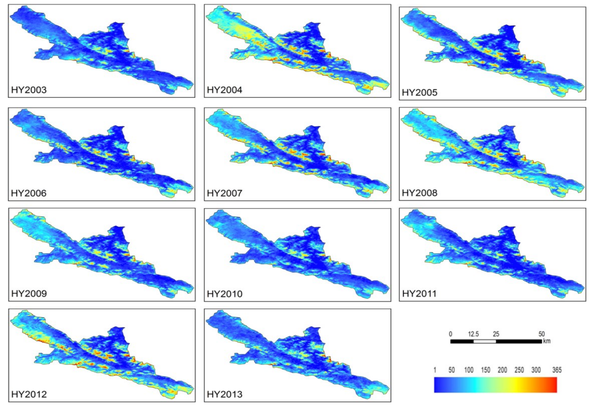


Figure 4. Snow covered days (SCD) maps from HY2003 to HY2013.

Relationship between LST and Tair

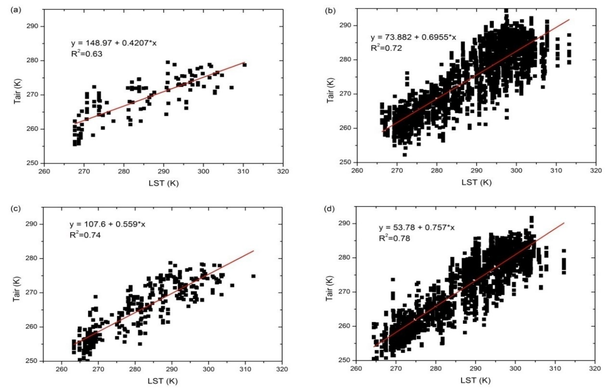


Figure 5. Relationship between LST and Tair for QiLian station for snow (a) and no-snow (b) observations; and YeNiuGou station for snow (c) and no-snow (d) observations. Linear regression relationship line and R^2 are included.

Correlation Between Snow Cover and Tair

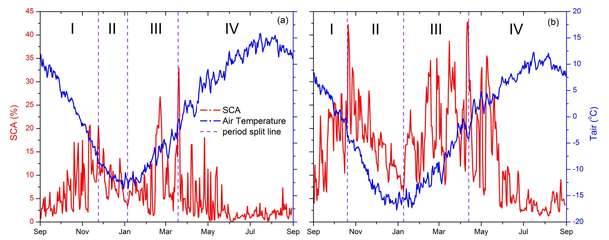


Figure 6. SCA(%) at elevation zones (a) 1708 m - 3000 m and (b) 3000 m -3500 m and corresponding mean air temperature (T_{air}) at Qilian station (a) and Yeniugou (b) from HY2003 to HY2013.

Table 1. Pearson correlation coefficients ($p<0.001$) between average snow cover area and mean air temperature during the four snow cover periods (indicated in Figure 6 and associated text) at Qilian and Yeniugou stations from HY2003 to 2013.

Snow Period	I	II	III	IV
Qilian	-0.72	0.77	0.54	-0.74
Yeniugou	-0.70	0.62	0.38	-0.52

Altitude Effect on Correlation Coefficient between Snow Cover and Climate Factors

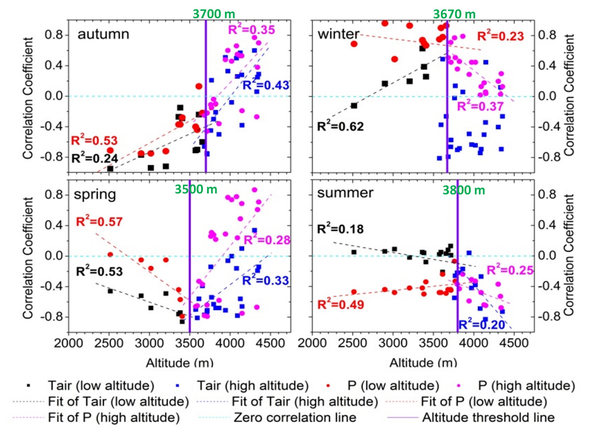


Figure 7. Altitude effect on correlation coefficient between climate factors (air temperature (T_{air}) and precipitation (P)). T_{air} and P at low altitude and high altitude are labeled with different color respectively.

Conclusions

LST and T_{air} in upper stream Heihe river basin show a strong relationship on both no-snow and snow covered area, with higher R^2 in no-snow area. The simulated T_{air} shows high negative correlation (99.9% confidence level) with SCA at period I and period IV. However, the high positive correlation (99.99 confidence level) between simulated T_{air} and SCA indicate the strong sublimation effect when the temperature becomes lower than freezing point (0 °C).

This study confirms that there is indeed a threshold altitude existing in the study area and that, as seen from the figure 7, the effects of T_{air}, precipitation, and elevation on snow cover are quite different in four seasons and the threshold altitude also differs slightly from season to season, but within the range of 3700 ±200 m. We summarize our finding from the figure 7 as below: at below the threshold altitude, both T_{air} and precipitation effects on SCA are negative factors, except in the winter season when both are positive factors; at above the threshold altitude, precipitation acts as a positive factor except in summer it is a negative factor, while T_{air} is negative factor except in fall it is a positive factor. We also provide some physical explanations on these phenomena.

Bi, Y., H. Xie, C. Huang, and C. Ke, 2015. Snow cover variations and controlling factors at Upper Heihe River Basin, Northwestern China. *Remote Sensing*, 7: 6741-6762, doi:10.3390/rs70606741